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GEOLOGY.

Notes Taken from the Lectures of Prof. W. B. Scott, Ph.D.

SECOND TERM, JUNIOR YEAR,

PRINCETON COLLEGE.

Some said, "Yes, print it;" others said, "Not so."
Some said, "It might do good;" others said, "No!"
—Bunyan's Pilgrim's Progress.

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INTRODUCTORY.

HISTORY OF GEOLOGY.

The origin of all science is the desire to know the causes of things around—earth, air, sea, sky, etc. The Greek, the Roman, the Assyrian, all tried to explain the origin of our universe by different beautiful cosmogonies. Every solution of a scientific problem resolves it into two factors—one known, the other a mystery. The mysterious again resolves itself into other and deeper mysteries: *e. g.*, though Newton expressed the law of gravitation by a formula, we can never fathom the mystery of *how* matter attracts.

In physical sciences, the starting point seems ever to have been astronomy. The motions and the beauty of the heavenly bodies early attracted the attention of men; and even their rudest astronomical observations were of practical value.

Geology is a science, the existence of which nine out of ten people do not even suspect. It is easy and natural to believe that the world has always been as it is, since all geological changes are so slow and occult that people do not notice them. Geological speculations have ever had an important place in philosophy.

The Egyptian Priests had a knowledge of geology. They knew that the hills along the Nile were filled with fossils. Herodotus mentions this fact; but we have no definite idea of how much they knew.

Anaximander [610 B. C.] gives the first germs of evolution. He says: "All mankind sprang from fishes." Some, even Cuvier, have erred in attributing too much to him—claiming that he held the doctrine that man was developed through all the lower forms; while he simply taught that man came from fishes, and gave no intermediate steps.

PYTHAGORAS is the first who gives us geological speculations of any value. Although none of his writings are extant, Ovid* has preserved many curious facts and fancies of the great philosopher. His general doctrine may be stated thus: Nothing perishes in this world; all things merely vary and change their forms. Although nothing retains long the same image, yet the sum of the whole remains constant. He said that the sea and land changed places. He shows, concurring with modern geologists, how valleys are cut out by water, and how floods wash hills into the sea.

ARISTOTLE, like other ancient philosophers, was interested in fossils, which were found in great numbers in the marble quarries. His dictum, the force of which is to-day being recognized by modern scientists, is as follows:

The slow accumulation of causes now in existence, produces, during the lapse of ages, great changes. Further, that the distribution of land and sea, in particular regions, does not endure throughout all time; and there is reason for thinking that the changes occur according to a definite system.

The Romans added little, if anything, to the knowledge of geology.

STRABO, living in the Augustinian age, expanded on the Greek philosophy, and gave some original ideas. One is especially important, viz.: It is proper to derive our explanations from things that are obvious, and, as it were, of daily occurrence—deluges, floods, rising of land in the sea.

The fall of the Roman empire threw a pall over all scientific study. For centuries men argued, narrowly, on the

*Ovid Metamor. Book XV.

Bible and Aristotle alone, and but little progress was made.

It is worthy of notice that the first awakening took place among the Arabs. They were enthusiastic in the pursuit of all the then known sciences.

AVICENNA, an Arab physician of Spain, wrote a book on the formation and classification of minerals. He said that some mountains were formed by the upheaval of the earth, and some by the enjoining land being cut away—perfectly sound inductions.

A REVIVAL OF THE SCIENCE began in Italy, in the beginning of the sixteenth century. The fossils turned up at Verona led many philosophers of that day to speculate upon them. Among them was *Leonarda de Vinci*, who ridiculed and exploded the idea that fossils were formed by the fecundating influence of the stars upon plastic hills.

REAL BEGINNING OF GEOLOGY.

FRACASTORO reasoned clearly and soundly, and gave us the real beginning of geology. It took three centuries for men to grasp the answers which he gave to the two great questions :

1. Are fossils the remains of organisms?

2. Can they all be accounted for by reference to Noah's deluge?

Men in those days chose absurd and paradoxical theories to defend.

The geologists, prior to 1740, were HOOKE and RAY, of England, STENO, a Dane, and many Italians. All of these failed until the beginning of last century, when HUTTON, who drove out all the former absurd fancies, took up Strabo's dictum, and although he took a narrow view, yet he is really the founder of the science.

WERNER, of Freiburg, a contemporary of Hutton, did the science more harm than good. He had many absurd ideas, and gained great control over his students. He however made some important advances in examining the rocks in his neighborhood, and *finding a certain invariable order prevailing.*

Wm. Smith, of England, a civil engineer, but a man of scanty education, also found that there was a regular succession of rocks; and he added the important discovery that *each rock was characterized by particular fossils.*

Hutton, Werner and Smith were the leading geologists of the last century, and from their discoveries we get the beginnings of the Modern Science of Geology.

For a century there were two contending schools, the Neptunists and Vulcanists. The former claimed that everything was precipitated from water; while the latter held that all rocks were formed by volcanic action.

RENAISSANCE.

In 1807, a society in London was formed with the open avowal that they would have nothing to do with speculation. About the same time some men in France laid the foundations of the science of paleontology. Four centuries gave to these men only two facts, but those were important ones:

I. That fossils are the remains of organisms.

II. Certain strata invariably contain certain fossils.

Lamark, Cuvier and Broginart, were the fathers of the science.

Cuvier discovered that there were fossils of *extinct* animals. This led to the generalization that there were several ages in the earth's history.

Lamark held the doctrine of evolution.

Cuvier held the doctrine of *catastrophisms*—deluges, hurricanes, volcanoes, etc. The succession of causes was broken. This theory is still held by some few conservative geologists.

Investigating but a small portion of the earth, and finding great gaps in the rocks, they were driven to this doctrine of catastrophies. Everywhere they found that the crust of

the earth had undergone changes that could not be accounted for by causes now in operation; they therefore concluded that at different times all things were destroyed, a new creation took place, and then another catastrophy, as before. To each interval of rest they gave the name of a geological period. The fundamental point was, that all these changes took place in a short time. This logically drove them to the doctrine of catastrophies.

The opposing doctrine introduced by Hutton, Stevenson and others, is that of *uniformity*, viz.: That in spite of apparent violations of continuity, the sequence of geological phenomena has been an uninterrupted one. All the vast changes are the results of slow operations during enormous periods of time.

Catastrophism is the result of the doctrine of short time. Uniformity results from the hypothesis of indefinite time. But the latter theory has been carried too far. The forces in ages past acted, no doubt, with greater intensity than the same forces now at work; *e. g.*, the tides were at one time from six to eight hundred feet high. The changes of to-day are the same as those of yesterday, but different in degree.

GEOLOGY.

GEOLOGY *is that science which investigates the history of the earth and its inhabitants, as revealed in its structure and interpreted by causes still in operation.*

The science began with the record of phenomena.

Geology may be divided into three departments:

I. Descriptive or Structural Geology.
II. Dynamical Geology.
III. Historical Geology.

STRUCTURAL GEOLOGY, OR GEOGNOSY.

Structural Geology is the study of the external form and internal structure of the earth. (Le Conte.)

LAND AND WATER.

The *Features of the Earth* are arranged systematically. The water is to the land as 11 is to 4. The land is crowded toward the north, and radiates from the north pole in three great lines; thus animals in ages past migrated from one continent to another. Taking as a pole a point in the British Channel, we can draw an equator dividing the earth into two hemispheres, one of land, the other of water.

The continental masses rise abruptly from oceanic depressions. The depth of the ocean is averaged now at 13,000 feet (over two miles). The Atlantic Ocean slopes gradually to a depth of 600 feet, then suddenly drops to 15,000 or 20,000 feet. Then a flat plateau, very level, stretches to the other side. Thus the apparent coast line often differs from the real; the latter being in the above case at the 100-fathom line. Elevate the British Isles 300 feet and they would be a part of the continent. Australia was once a part of Asia.

Average height of the land is 1,000 feet. Depth of ocean, 13,000 feet. Thus we have the following proportions:

Height of land			: depth of water			: : 1 : 13.
Area	"	"	: area	"	"	: : 1 : $2\frac{3}{4}$.
∴ Bulk	"	"	: bulk	"	"	: : 1 : 36.

ISLANDS.

Continental Islands are those which really form a part of the continental masses, *e. g.*, England, Australia.

Oceanic Islands. The bottom of the ocean is generally flat, with now and then a mountain raising its head and forming an island. Oceanic islands are always of coral or volcanic origin. Sedimentary rocks are not found in oceanic islands, and hence no continent has ever gone down into the ocean.

CONTINENTS.

These have a definite structure, which is recognizable even in the smallest of them.

The Laws of Continental Forms.

1. They always have high borders and a low interior plain.
2. The mountains run parallel to the coast lines. By this criterion, Australia is by some adjudged a continent.
3. The low central plains are where the great rivers flow.
4. The heights of the mountainous ocean borders are roughly proportioned to the size of the ocean which they face.

The Surface is, therefore, divided in four divisions.

1. *Lowlands*, comprising the portions of the earth's surface below the elevation of 1,000 feet.
2. *Plateaus*, the portions above 1,000 feet; *e. g.*, the plateau between the Rocky Mountain and the Pacific Range.

3. *Mountains* differ from plateaus in that they are irregular.

4. *River systems.* Upon the disposition of the Highlands and Lowlands depends the condition of the Rivers. Rivers take their origin in mountains or plateaus, continue to flow into the Lowlands, collecting into fewer and fewer channels, until they come to the sea in one trunk. All this is called a river system; *i. e.*, all the land drained by this final trunk.

Upon the disposition of these four divisions depend the climate, etc., of the continent.

COAST LINES. There seems to be some general law in reference to the courses or coast lines.

There are two courses on the earth, one northeast, the other northwest. All the coast lines, mountain systems and chains of islands follow these general directions. When these courses cross each other they meet nearly at right angles.

THE OCEAN.

The ocean is not a dead mass of water. There is a continual circulation through the ocean currents. The system of currents north and south of the equator is much the same.

The expedition of the Challenger did much to explain these phenomena. The temperature of the water at various depths was taken and recorded, and other observations made.

Two general laws have been deduced:

I. At the bottom of the ocean there is a continual influx of water from the poles to the equator. When the cold water reaches the equator it rises, becomes heated, expands and flows off (down hill) toward the poles.

II. The revolution of the earth causes another set of phenomena. The revolution at the poles is, of course, zero, and this gradually increases as one moves toward the equator, where it reaches its maximum velocity, or about a thousand miles an hour. Thus the water, as it flows north (in accordance with the 1st general law) moves into regions where the velocity of the earth's rotation is less and less, but it retains through its inertia much of its original velocity, and consequently moves toward the west.

To sum up: The general motions of the ocean currents depend—

1. Upon the difference of temperature at the equator and the poles.

2. Upon the different velocity of the earth's rotation at different latitudes.

Climate, therefore, depends not solely upon latitude. The oceanic currents constitute one of the prime elements; *e. g.*, the eastern coast of the continents are colder than the western.

It also depends somewhat upon the distribution of land and water. Sea breezes are formed thus: The land cools more rapidly than the water, and the air above the land is contracted, and the warm air from the sea rushes in.

The severity of our winters depends upon the prevalence of northwest winds, which, before reaching us, blow over large tracts of Arctic land. In Europe the same wind, coming from the sea, moderates the climate.

Hence, climate depends upon a concurrence of causes.

COMPOSITION OF ROCKS.

A rock is any constituent part of the earth's crust found in mass. The rocks are made up of a mechanical mixture of minerals; *e. g.*, Granite, Felspar, Mica and Quartz. As we analyze further and further we at last come to elements which cannot be divided.

Chemists divide all bodies into two classes: simple and compound.

There are sixty-three known simple elements. Only a few of these are important, geologically.

ELEMENTS :

Non-Metallic.		Metallic.	
Oxygen, . . .	O.	Aluminium, . .	Al.
Hydrogen, . . .	H.	Potassium, . .	K.
Silicon, . . .	Si.	Sodium, . .	Na.
Carbon, . .	C.	Calcium, . .	Ca.
		Magnesia, . .	Mg.
		Iron, . . .	Fe.
Sulphur, . . .	S.		
Chlorine, . . .	Cl.		
Fluorine, . . .	F.	Lithium, . . .	Li.
Phosphorus, . . .	P.	Barium, . . .	Ba.
Boron, . . .	B.	Manganese, . .	Mn.

OXYGEN (O), in weight, forms more than one-half of the crust of the earth. It supports combustion, and upon it all organic life depends. It is the important constituent of the air.

HYDROGEN (H), is very light, is seldom uncompounded, and is very combustible. It is the important constituent of water (H_2O).

SILICON (Si) is a solid; never occurs uncompounded in nature. It is the most abundant of all minerals, and the hardest mineral that occurs in quantities.

CARBON (C) is the main constituent of coal. The diamond is crystallized C. It has an intense affinity for oxygen when heated.

O, H, C and Si constitute 79 per cent. of the crust of the earth.

ALUMINIUM (Al) is the base of clay; used largely in the arts and is a light and strong metal.

POTASSIUM (K): very light, soft, and floats on water, takes fire easily, and is never free in nature; is main constituent of potash.

SODIUM (Na) bears the same relation to soda that K does to potash. It is the metallic constituent of salt. Found free in nature.

CALCIUM (Ca) is the metallic base of lime.

MAGNESIUM (Mg) is the metallic element of common magnesia.

IRON (Fe): symbol Fe, from Latin *ferrum.*

These six metallic elements, with the four non-metallic, mentioned above, are the most important constituents in the earth's crust. The rest are less important.

SULPHUR (S) is our common brimstone.

CHLORINE (Cl) is a yellowish gas. Common salt=NaCl.

BORON (B) is the base of borax.

Ca, K and Na are the alkaline metals.

Al, Ca and Mg are alkaline earths; form ordinary soil.

K and S are alkaline; make soaps fast, and turn liquid reds to blue.

The only two which occur uncompounded in masses are S and C. O occurs free in the atmosphere, but not in the earth.

PRIMARY COMPOUNDS

are direct combination of two elements: *e. g.*, H_2O.

There are two classes of bodies—ACIDS and BASES; these unite to form a SALT. A typical base is an alkali.

Compounds.	H_2O=Water. SiO_2=Silicic Acid or Quartz. CO_2=Carbonic Acid. H_2SO_4=Sulphuric Acid.
Alkalis, Alkaline, Earths.	Al_2OK_2O=Potash. Na_2O=Oxide of Sodium. CaO=Lime. MgO=Magnesia.

Compounds of Chlorine, NaCl=Salt.

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1. [illegible]
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3. [illegible]
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4. Dale
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5 [illegible]
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Compounds of Iron.
- Fe_2O_3=Hematite.
- $2(Fe_2O)_3\ 3(H_2O)$=Hydrate.
- Fe_3O_4=Magnetite, black oxide of Fe, or loadstone.

Silicant of Aluminum=$SiO_2Al_2O_3$.

MINERALS:

The several substances which make up the crust of the earth we call ROCKS; *e. g.*, even sand is called a rock.

Rocks are, for the most part, not *chemical* compounds; but are mechanical mixtures.

A MINERAL *is any substance occurring in nature, not organized by vitality, having a homogeneous structure and a definite, chemical composition.*

Chemical compounds are absolutely infinite in number, and vary greatly, one substance often replaced by and representing another; hence our formulæ are only true within limits.

Minerals composed of SILICON. QUARTZ=SiO_2 is most abundant of all minerals. Pure quartz, or rock crystals, have been much used in the arts; it is one of the hardest substances we know. There are infinite varieties, opaque and transparent. SiO_2 is the type of all minerals composed of silicon.

AMETHYST, colored purple, when very pure, is precious.

AGATE, made up of banded structure.

JASPER, formerly precious.

CHALCEDONY, made up of gelatinous silica.

FLINT or Silex, is non-crystallized; often dark and smoky.

QUARTZITE, made up of grains of crystal.

There are two forms of silica:

I. Soluble, or hydrated.

II. Insoluble, or crystalline.

If the first be precipitated, it becomes gelatinous, forms a solid and becomes insoluble. Is formed around geysers.

OPAL is hydrated, gelatinous silica, with more or less coloring matter. Found in lava streams.

Minerals composed of SILICATES, *i. e.*, a union of silica with a base, thus forming a salt :

GLASS is a silicate of Ca, K, or Na.

FELSPARS vary much, but are all compounds of Si, Al_2, O_5, with other substances, viz. : K, Na, Ca, and upon the presence or absence of one or more of these depends their classification—divided, somewhat arbitrarily, into two classes :

I. Acidic ; rich in SiO_2.

II. Basic ; poor in SiO_2.

ACIDIC FELSPARS :

Orthoclase (called so because of its cleaving at right angles) is the typical acidic felspar. Dull surface.

$(K_2O)\ (Al_2O_3)\ 6(SiO_2)\ 1:1:6.$

Sanidine is a glassy orthoclase, or a potash felspar.

ALBITE, white, is a soda felspar.

$(NaO)\ (Al_2O_3)\ 6(SiO_2)\ 1:1:6.$

Oligoclase, varied composition.

$2(RO)\ 2(Al_2O_3)\ 9(SiO_2)\ 1:1:4\frac{1}{2}$, R=either K, Ca or Na, but its quantity remains constant.

BASIC FELSPARS :

Labradorite. Dark greenish hue ; hard, iridescent.

$(RO)\ (Al_2O_3)\ 3(SiO_2)\ 1:1:3.$

Thus it has one-half as much silica as orthoclase. R usually=lime.

Anorthite. Lime felspar.

$(CaO)\ (Al_2O_3)\ 2(SiO_2)\ 1:1:2.$

MICA :

Important constituent of granite ; splits up into thin plates. Is wrongly called isinglass. Composition very variable :

$$\left.\begin{array}{ll} SiO_3 & 35\text{–}50 \\ Al_2O_3, & 15\text{–}40 \\ K_2O, & 8\text{–}10 \end{array}\right\}\text{Mica.}$$

Muscovite is a potash mica, found in Russia; is the mica of commerce.

Biotite contains Mg and Fe.

HORNBLENDE (from German *blende*—to deceive). Bi-silicates of one or more bases, viz.: Ca, Mg, Fe, Mn.

Two important forms are—

Hornblende, or *Amphibole*—Bi-silicate of Al and Fe; is a dark rock.

Augite, or *Pyroxene*. Difference is not a chemical one, but in the way they crystallize. Their color is a dark green.

☞ The hornblendes are associated with free quartz and both felspars, but Pyroxene is never found with free quartz or orthoclase, and only sometimes with the Basic felspars. Augite points out a Basic felspar.

Olivine is a silicate of Mn, dark in color, and is found in Basic rocks.

TALC GROUP:

Talc.

Chlorite.

They are essentially hydrated silicates of Mg.

Talc is a hydrated bisilicate of Mg with Fe and Al_2O_3. It occurs in foliated or laminated plates, and has been chosen as the standard of softness.

Chlorite is a single silicate of Mg; color, beautiful green, and in compound constitutes the very abundant Serpentine.

CALCAREOUS GROUP:

These are compounds of lime.

Calcite, one of the most abundant in nature, is a simple carb. of lime, $CaCO_3$. It makes up the great bulk of limestone. We can prove, in nearly every case, that limestone rocks are of animal origin.

Dolomite is a bicarb. of Ca and Mg. It is a question whether it is a mixture or a true chemical compound. Witherspoon Hall is built of Dolomite.

Gypsum (plaster of Paris) is a sulphate of lime, $CaSO_4$, $2(H_2O)$. It crystallizes in long rhomboidal crystals, clear like glass or mica, but not flexible.

Selenite is crystallized sulphate of Ca, with water in composition. When heated it falls into a white powder (plaster of Paris); mixed with water it hardens again, and is thus useful in the arts.

Alabaster, a form of gypsum, is used much in ornamental carving.

ROCKS.

A scientific classification of rocks is impossible upon any one system. A classification based on chemical composition or on structure is inferior to the one having for its basis the *mode of origin*. This gives us two classes:

I. *Non-crystalline* are composed, not of crystals, but of separate particles, more or less rounded and broken, which are held together by a cement or paste.

II. The *crystalline* are made up of distinct crystals, with sharp angles and edges, and these are held together by a cement not so plainly crystalline.

The texture of *non-crystalline* rocks depends upon the quality of the cement. If this is soft and not very abundant, we get a loose, earthy, or friable rock; if abundant and firm, we get a hard, solid rock. Sand is a rock with no cement.

We divide NON-CRYSTALLINE rocks, according to composition, into four classes:

I. Arenaceous (sandy).
II. Argillaceous (clayey).
III. Calcareous (limey).
IV. Carbonaceous (coal).

I. The *Arenaceous* rocks are made up of fine, loose quartz sand. When the grains are bound firmly, we call it sandstone. A conglomerate rock is composed of quartz

[illegible]

pebbles, and these pebbles are always rounded, as if worn by water. If the pebbles are angular, we get a rock called breccia.

II. In *Argillaceous* rocks the main ingredient is clay. Chemists are in doubt as to the composition of clay, but, in general, it is a hydrated Sil. of Al, $2(SiO_2)\ Al_2O_3,\ 2(H_2O)$. These clays are produced by the composition of Na and K felspars.

III. *Calcareous* rocks. Limestones are of two formations:

A. Chemical, called travertine. Limestone is a carb. of lime, and is soluble in water which contains a little carbonic acid (CO_2); the amount of the carb. of lime dissolved is proportionate to the CO_2 in the water. When a spring comes to the surface, and is released from pressure, it loses a part of its CO ; this loss weakens the dissolving power of water, and lime is deposited in the shape of Travertine. These chemical deposits never extend over large areas. Rome is built of Travertine.

B. The *organic* method is simply the accumulation of shells or the hard portions of lime-secreting animals. All *great* limestone formations were made in this way. Chalk and Carrara marble are the extremes of this series.

IV. *Carbonaceous* rocks comprise coal and graphite. They will be discussed later.

We divide CRYSTALLINE rocks, according to texture, into—

I. Glassy.
II. Microcrystalline.
III. Macrocrystalline.
IV. Porphyritic.

And according to structure, into—

I. Compact.
II. Pumiceous.
III. Scoriaceous.

Every crystalline rock has for one of its most important ingredients a felspar, either acidic or basic, and the classification of these depends upon the character of the felspar.

I. *Acidic* rocks have as their prevailing felspar orthoclase or albite, 1 : 1 : 6; oligoclase is often present, but not alone.

II. *Basic* rocks have as their felspars, labradorite, 1 : 1 : 3; anorthite, 1 : 1 : 2, and sometimes oligoclase, 1 : 1 : 4½.

III. *Intermediate* rocks lie between the two, defying all sharp lines of demarcation, composed either of a highly silicated felspar without free quartz, or a basic felspar with free quartz.

I. ACIDIC ROCKS.

1. *Quartzose Trachytes* consist of sanidine and quartz crystals, imbedded in homogeneous paste. They are divided, according to texture, into Obsidian, Rhyolyte, Millstone Porphyry, Perlite and Pumice.

2. Felstones consist of a mixture of orthoclase and quartz. Divided into Retinite, Felsite and Elvanite.

3. Granites consist of free quartz, orthoclase and mica. Divided into Granite and Syenite, *i. e.*, hornblendic granite.

Table of Acidic Rocks.

	Quartzose Trachytes.	*Felstones.*
Glassy Form:	Obsidian.	Retinite.
Compact Form:	Rhyolyte.	Felsite.
Crystalline Form:	Granular and Porphyritic Trachytes.	Granular and Porphyritic Felstones.
Coarsely Crystalline Form.	Elvanite, Syenite, Granite.	

II. BASIC ROCKS.

1. *Diorites* consist of oligoclase and hornblende. These show all four textures. Divided into Alphanite, Granular Diorite and Porphyrite.

2. *Basalts* consist of Labradorite and Pyroxene or Augite Divided into Tachylite, Basalt, Dolerite and Gabbro.

III. INTERMEDIATE ROCKS

Combine the characteristics of both the other classes; *i. e.*, Basic Felspar and free quartz, or acidic felspar and no quartz. Divided into Quartzless Trachytes, Andesite, Dacite and Hyposyenite.

Stratification. The parallel layers of which the earth's crust is formed are called strata. This formation is by no means universal.

Relation between stratification and texture. In a very large majority of cases if a rock is stratified it is non-crystalline, and if crystalline it is not stratified. There are some apparent exceptions.

In many rocks we shall find fossils. They may be the hard parts of animals or parts of plants. A non-crystalline stratified rock generally has fossils, whereas, crystalline unstratified rocks are unfossiliferous. Hence:

Crystalline.	Non-crystalline.
Non-stratified.	Stratified.
Unfossiliferous.	Fossiliferous.

The study of Structural Geology will be resumed later on.

DYNAMIC GEOLOGY.

We can trace, by the formations of rocks, all the world's history.

Dynamic Geology is the study of the forces now acting on the earth. It is the physiology of our planet. It must busy itself with the present order of nature. We study the causes, and classify them into—

I. Atmospheric.
II. Aqueous.
III. Organic.
IV. Igneous.

Dictum: *No phenomenon in nature is the result of a single cause, but of a combined series of causes.* When we examine the effects of all these causes singly, we overlook their balancing and modifying effects upon each other.

I. ATMOSPHERIC CAUSES.

These are *wind*, *rain*, *frost*, *snow*, etc. Under atmospheric causes we study the chemical, in distinction from the mechanical effects of water.

Rain. Its important effect is the formation of soil. Soil is formed by the decomposition of rock. Every rock consists of two kinds of constituents: soluble and insoluble. The soluble matter is slowly dissolved out, and what remains crumbles.

Frost is an agent of immense power. It depends upon the fact that when water freezes it expands. It is a molecular force. Every rock is porous and contains water. Where there is a crevice the water collects, freezes and breaks off large pieces.

Wind causes sand drifts, which protect the coast. Bodies of shallow water are often filled with sand by action of wind, and so reclaimed from the sea; *e. g.*, Yarmouth, Eng. In Bermuda, sand glaciers are stopped by grass growing upon them. Wind is an important factor in the formation of Coral Islands.

II. AQUEOUS CAUSES.

These are the mechanical effects of rain, rivers, oceans and of ice, in their three-fold work of:

1. Erosion, or the work of cutting into the land.
2. Transportation, or the work of carrying sand, rock, etc.
3. Deposition, or the work of final throwing down.

Rain sinks into the ground and does chemical work of soil-making, which has been considered under atmospheric causes. Secondly, the mechanical effects of that part which rushes through systems of rivulets and streams.

Rain is not a very important geological mechanical agency. Its greatest mechanical effects are seen in dry climates: *e. g.*, Monumental Park, with its needles of stone, capped with hard pieces of shale and slate. They are monuments of the amount of the erosive power of rain.

The bad-lands of the West are a species of rain-sculpture.

Rivers. These are most important; their power is enormous.

Erosion:

In 1603 a violent eruption of Ætna dammed up the Simeto. In cooling, the lava became as hard as basalt. In two centuries, the river had cut a gorge 50 feet deep, 100 or 200 feet wide, and several hundred yards long.

Niagara is the best example of progressive erosion. The river has cut a gorge from Queenstown to the base of the falls, a distance of seven miles. Estimated rate at present is from one to three feet a year.

The upper strata is of hard, sandy limestone; lower down is a soft shale, which is continually acted upon by the spray and frost. It is, therefore, continually working back from the hard rock above, which, from time to time, breaks off in huge masses.

Proofs that the gorge has been cut by the river:

1. Niagara has been watched for 150 years. The part cut during this time is precisely like the rest.

2. Strata on both sides coincide.

3. There are alluvial deposits, filled with shells, above the falls. Precisely similar deposits, with similar shells, are found all along the top to the gorge below the falls—thus proving that the work of erosion has taken place since the introduction of the present inhabitants of the river.

Other examples are the deep canons of the West, some of them forming perpendicular walls 4,000 feet high.

Erosive power varies as the square of the velocity. The velocity depends upon many conditions, but chiefly upon the slope of the bed. The final shape of the ground is due, in every case, to the sculpturing of the erosive power of water. What are the tops of the Appalachian Mountains now were once the bottoms of valleys, as proved by the curvature of the strata.

Transportation:

Specific gravity of rocks is 2.5 to 3. They thus lose, when immersed in water, from one-half to one-third of their weight.

Water, with bottom velocity of 3 in. per second, can take up fine clay; 6 in. per second, gravel; 3 ft. per second, stones the size of an egg.

Transporting power varies as the sixth power of the velocity. This explains the terrific power of a flood. As soon as the river expands, the transporting power is lessened, and it drops its burdens.

Running water, of itself, cannot erode anything but the loosest kind of soil. Its erosive power is due to the sand and gravel it carries along by the transporting power. Flowing water is the power; the sand and gravel the instruments. Not only do the pebbles cut rock, but they grind each other; and, hence, the finer sand near the mouths of the rivers.

It is easy to understand how a mountain stream can erode its bed; but it is not so plain why a river is not choked up in a level country. It is explained by the influence of tributaries.

Two equal streams, when united, do not occupy a bed of double surface, because the addition of the branch augments the velocity in the same ratio as the volume. There are three reasons for the above law:

1. After the junction, the same amount of water has the friction of two banks, instead of four. Element of friction is very important.

2. The main body of the stream is further away from the banks, and so is much less impeded by the friction.

3. A greater mass of water, moving with greater velocity, erodes deeper into its bed.

Thus the surface of running water, as it approaches the sea, grows smaller and smaller.

Minor Phenomena of Rivers:

Sinuosities, or meanderings. Rapidly flowing rivers are comparatively straight; but when the river enters a plain, "some portion of the bank, a little softer than the rest, will be excavated; this will reflect the current obliquely across to the other side, which will become similarly excavated. Thus the current is reflected from side to side, increasing the excavations. In the meantime, while erosion is progressing on the outer side of the curves because the current is swiftest there, a deposit is being made on the inner side because there the current is slowest. Thus, while the outer curve extends by erosion, the inner curve extends, *pari passu*, by deposits." Often a river will take a short cut, abandoning some of its windings, leaving lagoons, as in the lower Mississippi.

Deltas are portions of land at the mouths of rivers, and reclaimed from the sea by their agency. They are formed in lakes and in tideless or nearly tideless seas.

The still water of the sea checks the velocity, and so the river deposits its sediment, until at last it appears above the level of the sea; *e. g.*, nearly the whole State of Louisiana is a portion of the delta of the Mississippi. We can prove that the mouth of Mississippi was once at Cairo, and that all the valley below was partially formed by the river.

Extent of the deltas of the Nile and Ganges is estimated at 20,000 square miles; that of the Mississippi at 12,300. The amount of material carried annually into the Gulf of Mexico is about 755,000,000 cubic feet; enough to cover a square mile twenty-seven feet deep. When rivers flow into lakes they tend to fill them up and to convert them into meadow land; *e. g.*, Rhone and Lake Geneva. Here the delta has advanced one and a half miles since Roman times. The Rhone has another delta in the Mediterranean, which has advanced thirteen miles during the Christian era. The delta of the Poe has advanced twenty miles since the time of Augustus. The Mississippi delta advances one mile in sixteen years. It is estimated that in 4,000,000 years the Mississippi will carry its whole basin into the sea.

Only finer materials are found in deltas, because:

1. The coarser sediment is left higher up.

2. The grinding process is continually at work until all the material is deposited.

Bars are formed in rivers which empty into estuaries or the open ocean. The transporting power is lost, and "the sediment is thrown down as soon as the tidal current comes in contact with the open sea, and is checked by it." A second bar is formed where the current water of the river meets the tide water of the estuary; this marks the mouth of the river proper; *e. g.*, the mouth of the Hudson river is six miles below Albany. The estuary meeting the sea forms another at Sandy Hook.

OCEANS. Action of *erosion* is carried on by two agencies: waves and tides.

The action of *waves* is confined to coast line; in a storm their force is tremendous, the pressure of a wave being often several tons to the square foot. As the coast recedes, by the action of the waves, there is left a submarine platform. No rock is hard enough to withstand the action of the waves, the sediment is carried away, and thus we find that sandy coasts are nearly always advancing.

The action of *tides:* "The tide is a wave of immense base, and three or four feet in height in the open sea, produced by the attractive force of the moon and sun on the waters of the ocean. The velocity of this wave is very

great, since it travels around the earth every twenty-four hours." Thus its erosive power is like that of the waves: *e. g.*, coast of Cape May retreats about nine feet per annum. The wearing action of waves is confined between high and low tide marks. The place of minimum action is just above low tide, because that part is protected longest. The maximum point is just above half tide, since it is longest exposed to the activity of the waves.

Action of *Transportation:*

Ocean Currents. They are too weak and flow too slowly to carry anything but the finest kinds of sediment; they are, also, too remote from the coast. Submarine banks are formed where two sediment-bearing currents meet. Sediment from the land never reaches the bottom of the deep ocean. Though the people of the *Challenger* drew up sand from the deep sea, they afterwards found that it had blown from the Sahara.

Transportation by *Waves.* This power is enormous, but limited in depth and extent. Along the Atlantic coast, the the sand is gradually working south; the trend of the coast is oblique, and the waves coming from the east are deflected toward the south, bearing the sand with them. The same thing is happening in Lake Michigan. All wave-worn materials are rounded—never angular. As soon as submarine banks come near the surface, the waves break and begin to throw up material on the leeward side. Wave-formed islands are seldom more than fifteen feet high.

Recapitulation: (1.) The sediment brought down by rivers is nearly all deposited in shallow waters.

(2.) The small amount of sediment carried by ocean currents is all deposited near the shore, none of it reaching the deep sea.

(3.) The tides and waves all work shoreward, beating back the material brought down by the rivers.

Hence, the sediment of the land is all deposited on the submerged margins of the continental platforms. Dana's general law: No continent can contribute to the sedimentary formations of another, except by the agency of floating ice.

Stratification is produced by the sorting power of water. In the course of a river, as it decreases in velocity, the coarsest sediment is first dropped, while the finest is carried farthest. In stratification two factors are necessary: (1.) A heterogeneous material. (2.) An intermittently acting cause. Both of these are always present in nature. Every river is an intermittently acting cause, for its velocity and volume are constantly varying with the weather and the seasons.

Law: All sedimentary deposits are stratified, and conversely, all stratified deposits are of sedimentary origin.

Layers of ashes about a volcano form only an apparent stratification.

Strata are nearly always found in horizontal layers. There are two important exceptions. First, where a rapidly flowing river empties into a basin, the delta and its layers are oblique. Secondly, current bedding. The beds all dip downward in the direction in which the current is flowing. Nearly every sandstone shows traces of this oblique formation.

Hence, sedimentary rocks are formed:

(1.) By the decomposition of an antecedent rock into soil by chemical means. (2.) By transportation of this material by running water. (3.) By its deposition in quiet water. (4.) By consolidation.

ICE. The work of river and shore ice is insignificant in comparison with that of glaciers and icebergs, which are of great geological importance.

Glaciers are accumulations of ice descending by gravity along valleys from snow-covered elevations. They are, in fact, ice rivers, which are the necessary outlets for the accumulations of snow that are continually increasing above

the snow line. The "snow line" around a mountain is the line where the annual thawings and freezings balance each other. There are *four* conditions necessary for the formation of a glacier: (1.) The region where it is formed must extend above the snow line. (2.) There must be an abundant supply of atmospheric moisture. No glaciers are formed on the northern side of mountains, since it is usually the south winds that bring rain and snow. In the Rocky Mountains there are no glaciers on account of the dry atmosphere. (3.) There must be a difference in temperature between Summer and Winter. (4.) The conformation of the ground must be favorable. A smooth cone could never be the seat of a glacier. If one or more of these conditions be wanting, the snow is gotten rid of by other means.

Conversion of snow into hard, blue ice. Snow is a mass of transparent, colorless crystals, between which are great quantities of air. Whiteness always results from the irregular and intimate mixture of some transparent mass with a gas. Ice is built up of the same crystals in actual contact, while in snow they are separated by air. Hence, to get ice from snow, we must get the crystals in contact, by driving out the air. Tracing a glacier from its foot, we will find every transition, from hard blue ice to freshly-fallen snow. In Summer, the direct rays of the sun partially melt the superficial layer, and the water trickles down through the snow beneath. Superficial melting, percolating water and nightly freezings are the three steps which give us *neve*, which is firmer than snow and yet opaque. The enormous pressure of the superincumbent mass, forcing out the remaining air bubbles, gives us pure ice.

Laws. (1.) The flow of glaciers resembles that of a river or other fluids. The least change of level produces a crevasse. This never reaches the bottom of the glacier, and always remains at the same place. Marginal crevasses are those formed along the edges of the glacier, and point towards the middle and up stream.

(2.) The movement of a glacier is faster in the middle on account of the friction at the sides. Friction also causes the top to move faster than the bottom.

(3.) When a glacier moves around a curve, the convex side moves faster than the concave.

(4.) When the channel abruptly narrows, the ice is heaped up above the narrows, and then flows with an increased velocity. The rate of motion ranges from two to fifty inches per day. The lower limit of a glacier is where the melting power and rate of motion exactly balance each other, and from that end there flows a glacial river. As soon as a glacier descends below the snow line, the top begins to melt off, and it becomes thinner and thinner.

Geologically, they furnish transportation. The surface of a glacier is covered with masses of earth and stones, called moraines. The debris along the side of a glacier is called a lateral moraine. A medial moraine, the debris in the centre, indicates the union of two or more branches. At the lower end, these stones are emptied into a heap called a terminal moraine. By this, we are able to tell where a glacier has been, long after it has disappeared. Everything in respect to a glacier is a floating body. All deposits formed by the agency of glaciers are unstratified.

It is *colder on the top of a mountain* than lower down for two reasons: (1.) The thin and dry air at the tops of mountains does not protect them against radiation. The atmosphere acts as a blanket to the earth; while it allows the ordinary rays of the sun to pass through without much loss, it does not allow the dark heat-rays to get out. Near the sea level, where the atmosphere is dense and moist, the earth is protected against radiation, and retains the most of its heat. On the other hand, when we ascend a mountain, both these causes are absent—the atmosphere is very light and dry,

and, as fast as the earth is heated, it loses its heat by radiation. (2.) When air is condensed it becomes hot; allowed to expand, it becomes colder. A current of air, driven to the top of a mountain, by expansion, deposits its moisture in the form of snow or rain. The snow line depends not only upon the cold, but also upon the amount of moisture.

Why glaciers move. A glacier moves as a viscous mass—not as a solid, gliding down a slope. Forced down the slope by the enormous pressure above, it yields in two ways: First, by breaking and freezing again; and, secondly, by the yielding of its particles. The friction of a glacier in its bed produces no small amount of heat, which tends to melt the glacier where the compression is greatest, and by this means the motion is accelerated.

Erosion. By their immense weight and unyielding form, they act as a plow. This power is increased by rocks and stones frozen in their bottoms, scratching the rocks over which they pass. The grinding of these stones produces the finest kinds of mud; and hence, every glacial stream is milky, containing an enormous amount of sediment. They grind hard and soft rocks alike. The passage of a glacier over a rock scratches it with parallel striations, by which the direction of the glacier can be determined. The whole topography of N. A. was modified by glacial action.

Icebergs are always formed from glaciers. They are pieces of glaciers, pushed into the sea and broken off. Those from the north are fantastic in appearance, while those from the south are regular and tabular. They carry masses of rock and boulders, thus furnishing the only way in which one continent may contribute to the sedimentary formations of another.

Chemical Causes. Though rain-water is a great agent in dissolving rocks, most of it sinks into earth and appears again in springs with something in solution. There is no perfectly pure water in nature. In most rocks the insoluble matter predominates, but in some, such as limestone, the whole rock is soluble. On account of the dissolving power of water, in all limestone regions we find immense caves hollowed out, always with water flowing at the bottom. An outcropping of limestone often swallows up a number of small streams. *Laws:* (1.) The dissolving power of H_2O is proportional to the amount of carbonic acid gas which it contains. (2.) The amount of gas that water contain is proportional to the pressure to which it has been subjected, and the lowness of temperature.

Water coming to the surface escapes from pressure, loses some of its gas, and a corresponding portion of its dissolving power; hence, the lime contained in solution is thrown down in the shape of travertine.

Salt Deposits. Salt lakes are formed in two ways. First, by the isolation of a portion of sea water. Secondly, by the indefinite concentration of river water, which always contains some salt. The evaporation of a salt lake balances the influx of fresh water, and the salt is thrown down. The first effect in the evaporation of these lakes is the strengthening of the brine. When the brine is sufficiently concentrated, gypsum is deposited, and upon this we get beds of salt. These are the deposits of dry weather, when the evaporation exceeds the supply of fresh water. The season of high waters deposit a layer of sediment. Thus the layers gypsum, salt, sediment, are repeated again and again.

III. ORGANIC CAUSES.

Organic causes are the effects which animals and plants have upon the globe, but chiefly in rock making. The igneous agencies tend to counteract the aqueous effects, but they cannot replace the soluble matter which is borne away in solution. Here we have organisms that are able to extract these soluble forms of matter from the sea, and give them back to the land in the shape of rocks. *Plants*

have a protective effect against disintegration. The mango tree grows in the deposits of the Amazon, along the coast of Guinea, and their long roots keep the tides from bearing away the newly-made land. Again, plants furnish actual contributions to rocks. All our coal beds are accumulations of plant life. All limestones are formed by *animal agencies.*

(1.) Rhizopoda are masses of protoplasm, performing all the functions of animals. They have the power of secreting beautifully-marked shells. Those that secrete limestone are called *Foraminifera.* The sea bottom, from 200—2,500 fathoms, is covered with a gray, oozy mass, made up of these foraminifera. Lower down, the water, under so great pressure, contains enough carbonic acid gas to dissolve them. (2.) *Mollusca* leave their shells in quiet water, free from surf. They are borne away, broken up by the water, and cemented together. (3.) *Crinoids.* Some of these are fixed, others free, but all secrete great quantities of lime. They are the most common of fossil animals. (4.) *Radiolaria* secrete quartz, and we find great accumulations of their shells.

Corals belong to the group Cœlenterata. They are the most important of the organisms whose remains have a part in the formation of the earth's crust. In the order of being, it is below the insect. The polyp resembles the sea anemone. The body is a leathery sort of sack, with a fringe about the top, composed of three distinct and important membranes—the ectoderm, entoderm and mesoderm. A folding in of the mesoderm forms a digestive tube. They have no organs of sense except touch. In the coral-making species, the calcareous secretion is always deposited in the mesoderm, *inside* the body. A section shows the inner convolutions, called mesenteries, between which are the septa or lines of calcareous substance.

Reproduction. (1.) The sexual, which is invariably by means of eggs. The eggs of the female are impregnated by the spermatozoa from the male. The young coral has power of locomotion, and attaches itself to a rock. (2.) Non-sexual. *a.* Budding. A bud appears on the side of a polyp, having the three membranes. Later, a mouth and a row of tentacles are formed. The bud detaches itself, except when they form a colony. *b.* Fission. Here the growth of the disc is not limited. The mouth elongates, a partition divides it, and, reaching the outside, new tentacles are formed. When the fission is regular, we have beautiful, star-shaped corals. In brain-coral, the disc elongates into many mouths before it divides. Life and death go on together in the growth of coral colonies. We find trees of coral ten or twelve feet high, with only a few inches living at the top—all beneath being dead. Brain-corals grow fifteen to eighteen feet thick, and have but about a half inch living on the outside. Corals grow till they reach the level of the sea. 95—98 per cent. of coral is pure lime.

Reefs—conditions of formation. (1.) They cannot grow where the mean temperature of any Winter month is below 68° F. (2.) They cannot grow where the depth of water is over one hundred feet. (3.) The water must be clear and salt, and hence they never grow at mouths of rivers. (4.) They must have surf. They grow fastest where surf and breakers are highest. Broken water contains more O, by which aquatic animals live. The bottom parts of the coral are continually dying, and are broken off by storm waves, even when one hundred feet under water. Washed about, they are ground fine enough to be cemented into a hard rock. Hence a reef is formed from the debris of innumerable coral beds. Corals extract the lime from water, and prepare it for the mechanical effects of wind and water. The rate of the accumulation of coral reefs is one of extreme slowness—some have estimated at one-sixteenth of an inch per year. Mollusks, crinoids, rhizopods, and other lime-secreting organisms, aid in the formation of a reef.

Four methods of limestone formation. (1.) When the growing organisms remain undisturbed and the interstices are filled up with a fine calcareous mud, brought by the currents. In these we often find the colonies intact. Beds made by this method are usually cavernous. We cannot obtain any quantitative standard from the present work of corals. (2.) When the whole mass is ground to fine sand and mud by the action of the waves. It becomes hard and compact in layers, and does not contain a trace of a fossil. (3.) Coral Rag is a coarse conglomerate, made up of bits of coral, roughly broken and cemented together. (4.) Beach-rock is made up of loose coral sand thrown up by the waves, and has a curious formation. As the waves dash up they send spray, bearing lime in solution, beyond their own mark; the spray evaporates, and leaves a thin layer of calcareous matter around a grain of sand as a nucleus. Around a reef are formed all the products of wave-action, from the coral rag to the finely-grained rock, showing no trace of organization. When growing corals reach the limit of low tide, all growth ceases. The mechanical growth goes on faster than ever. All that part of a coral reef above the surface is of wave-formation. Seeds lodge there, and germinate. The cocoanut palm is the first tree that appears on a reef.

Coral Formations are classed under three heads: (1.) A Fringing reef is attached closely to the land. (2.) A Barrier reef is some distance from the land, separated by a narrow channel. The great reef of Australia is more than 1,000 miles long, and shows a breadth of 80 miles. (3.) An Atoll is a ring of coral standing alone in the sea. In the ring there is a lagoon. For a long time the formation was inexplicable, the water being thousands of feet deep around them, and it being known that coral could not live below a hundred. They are explained by the fact that some islands, having fringing reefs, sink beneath the waves, but not faster than the coral grows. These reefs change from fringing to barrier, and the sinking continues until the tops of mountains disappear. This we can prove (1) by dredging up coral from great depths, which is a proof that there has been a subsidence; and (2) by tracing all these stages in the islands of the Pacific. All the coast of Florida, from the Everglades southward, has been one barrier reef after another, the distance between the barrier reef and the land being filled with the sediment from rivers. ☞ A barrier reef is not always a submerged fringing reef.

Earth Worms consist of a series of cylindrical rings, provided with bristles for locomotion. The mouth leads into an expanded pharynx, joined to a long gullet opening into a muscular gizzard, where "the food is literally *ground.*" They burrow into the earth by wedging their heads between the loose particles. If the earth is too hard they swallow it, easily passing it through their straight intestines in the shape of small, round, convoluted masses called worm-castings. Though worms ordinarily live near the surface, in cold or dry weather they go as deep as seven or eight feet. They are continually bringing up fresh masses of earth, since they always come to the surface to deposit their castings. They are found in every part of the world. From experiments, Darwin calculated that they deposit a layer over the earth one-tenth to one-sixteenth inch in depth. Thus, by their agency, the surface of the earth is continually changing, and anything spread over it is soon covered. The whole of our vegetable world has passed again and again through the bodies of worms, gaining in fertility.

CLASSIFICATION OF DERIVATIVE ROCKS.

According to the *manner of their formation*, we divide them into:

I. MECHANICAL. Matter in a state of suspension.

II. CHEMICAL. } Matter in solution.
III. ORGANIC. }

According to the *circumstances of formation*, we again divide into:

I. Marine.
- Litoral (formed in shallow water next shore).
- Thalassic (formed in water 100 fathoms deep).
- Abyssal (formed in deep sea).

II. Estuarine (formed in estuaries).

III. Lacustrine (formed in fresh and salt water lakes).

IV. Terrestrial.

Marine. *Litoral* are wedged-shaped masses, with thick end in shore, and have but few fossils.

Thalassic sand is replaced by finer mud and clay. Limestone is formed further out from the accumulations of calcareous organisms.

Abyssal. From 200 to 2,500 fathoms we find the bottom of sea covered with gray ooze of foraminifera. At depths of 2,500 fathoms the water is charged with carbonic acid, so that it dissolves the deposits, and red clay takes the place of the calcareous organisms. Pumice-stone from volcanoes floats out to sea, becomes water-logged, and sinks. We can find close parallels to the Litoral and Thalassic, but there is no representative of Abyssal rocks on the land. This goes to prove that the deep sea has never become dry land. Nor is there any such thing as a submerged continent.

Estuarine consists of wedge-shaped, interlacing strata; are full of cracks, and marked with ripples; possess characteristic fossils. They radiate in fan-shaped masses from mouths of rivers, by which we trace ancient mouths.

Lacustrine. The sediment of a lake is usually supplied by several rivers, and at the mouth of each we find a fan-shaped mass of conglomerate. Geologists find such masses near each other, and by joining them they can easily map out an ancient lake. Near the center of such a lake they generally find a deposit of creamy shale containing fossils.

Estuarine rocks all radiate from a center outwards, while in Lacustrine the finer materials all converge toward the center of the lake.

The following are three characteristics of salt-water lake deposits:

1. We find great masses of chemical deposits, as gypsum, dolerite and salt.

2. The rocks are, for the most part, barren of fossils—because few or no animals can live in such lakes, on account of the presence of oxide of iron.

3. They have a prevailing red color. The red sandstone from these lakes is not, properly speaking, red stone, but each grain is painted, as it were, by the oxide of iron (Fe_2O_3). Few red rocks have fossils.

IV. IGNEOUS CAUSES.

The atmospheric and aqueous causes are leveling in their tendency. The *igneous causes*, on the other hand, tend to increase the height and extent of the land and the depths of the ocean; *i. e.*, to exaggerate the inequalities of the earth's crust. All the igneous agencies have their origin in the internal heat of the earth.

Igneous agencies are three:

I. Volcanoes.

II. Earthquakes.

III. Slow Alterations in the earth's crust.

Volcanoes are not (as is popularly believed) necessarily mountains, do not burn, do not emit fire, except under peculiar conditions. *A volcano is a cavity leading into the interior of the earth, through which various molten and gaseous substances are ejected.* When a mountain is present, it is the product and not the cause of the phenomena; it is a cone piled up by the volcano. We see three forms of activity going on: (1.) Steam (not smoke) issuing in loud puffs added to the clouds of vapor. (2.) Masses of white molten material flow a short

distance and cool in lava. (3.) Bubbles break and steam is emitted.

Bits of cooled lava are thrown up and fall. They are sometimes popularily called "volcanic ashes," but are not properly ashes.

There are three essential conditions of volcanic phenomena:

1. Communication with the interior of earth.
2. Presence of hot materials below.
3. Existence of great quantities of imprisoned steam.

The expansion of imprisoned steam is the cause of the activity of volcanoes. A similar phenomena may be witnessed going on in a pot of boiling oat-meal.

The appearance of flame, issuing from a volcano at night, is merely the reflection of the molten material upon the clouds of vapor and steam as they rise from the crater. Combustion has nothing to do with the energy of a volcano. During eruption of Vesuvius, in 1872, valuable facts were gained. Vapor rose to the height of four miles, and huge boulders were carried up with it. The mountain was rent in great fissures, and masses of lava issued from them. Every eruption was followed by great masses of steam, showing that it was the active agent. Before and during the eruption, earthquakes were frequent in the vicinity.

Electrical phenomena often accompany eruptions. The ejection of the steam and its subsequent condensation, is followed by much rain, which is often more destructive than the lava; for the latter is confined in its course, while the rain, mixing with the fine volcanic dust, forms great mud streams, which often overwhelm towns and villages. It finally sets in a firm rock mass.

The kind of eruption is determined by the quality of the lava. In Hawaii, the lava is very fluid—almost like water; so the eruption is quiet, and the lava runs long distances, making the slope of the cone very gradual. Long, flexible threads are blown out like spun glass. In Vesuvius and Ætna, the lava is more viscous, does not flow as far, and the eruption is of an explosive character. The form of the cone depends upon the character of the lava; the more viscous the latter, the steeper are the sides of the cone.

To sum up: Steam is the sole agency; and the character and appearance of the volcano depends upon the kind of lava.

Products of Volcanic Action are of three kinds:

1. Fluid, or molten lavas.
2. Solid, or fragmental rocks and ashes.
3. Gaseous.

Fluid Products. In molten lava, the fluidity is variable, and rarely perfect. A lava stream is a hot mass, containing crystals; it is partly solid, partly fluid—its fluidity depending upon the amount of water present. An aquo-igneous fusion decomposes rock and sand at a much lower temperature than fire alone. Rock, in a volcano, is melted by super-heated water under pressure.

Fluidity also depends upon the temperature and chemical composition; acidic lavas being much less fusible than basic. The first gives a doughy dome around crater, while basic gives us longer and longer streams. The lava stream flows along over itself, as tar; bubbles of gas escape, making a rough vesicular or cindery layer, called the scoria, which appears on both top and bottom of the stream. The center cools under pressure, and so slowly that complete crystallization takes place. Hence, the exterior and interior of a stream are very dissimilar. The terminus is of obsidian, a glassy, volcanic rock. When lava is forced in between two strata of rock, it is called an intrusive sheet, and the pressure prevents the formation of the frothy scoria.

There is no essential difference between modern lavas and the crystalline rocks formed in all ages of the world. All the lavas have a felspar as one of their constituents. It is

impossible to prove (as some geologists have attempted) that the lavas of different ages are of different chemical composition. It is true, ancient lava streams have been exposed for far longer periods than modern ones, and so have undergone greater changes.

Lavas are often jointed. They may be irregular or beautifully regular, as in the Giant's Causeway, Fingal's Cave, quarries along the Rhine, and at Mount Holyoke, on the Connecticut river. When the rock splits in three cracks from a center, a series of hexagons is formed; in four cracks, a series of squares or rhomboids; and when it splits in six cracks, a series of triangles. It obviously requires less work to split the rock into hexagons than into any other figure; hence, it is the commonest formation.

Fragmental Products and the solid ejections from a volcano. Huge boulders and smaller masses are hurled by the explosion of the steam into the air; they fall back, to be ejected over and over again, and are thus ground to fine dust. It was dust (and not ashes) that overwhelmed Pompeii in 79 A.D. It frequently darkens the air at mid-day. Pumice, which is a frothy rock, floats out to sea, becomes waterlogged, and sinks. It is the chief contribution of the land to the deep sea. The red clay of the deep sea arises from the decomposition of this acidic rock.

Gaseous Products are not very important geologically. They are CO_2, N, H, H_2S, HCl and SO_2.

In every volcano there is a *cycle of operations*. The activity begins, gradually rises to a maximum, and then dies out, to begin again as before.

Monto Nuevo, north of Naples, was formed in 1538. The ground for a long time had been disturbed by shocks, a depression took place, cold water flowed out, followed by warm, and next a stream of lava. In three days the scoria built up a hill about four hundred feet in height.

The shape of volcanoes depends somewhat upon the fissures.

These often occur miles in length, through which great floods of lava issue. A number of volcanoes often arise from a single fissure, and again, many radiate from a common center.

Number and distribution of volcanoes. About 300 to 350 active ones have been noticed in historical times. Including those that have been active at previous times, we can count a thousand. Temporary openings, geysers, hot springs, etc., are counted by millions. The distribution of volcanoes is irregular; Europe has one (Vesuvius); Mediterranean Islands, 6; Africa, 10; Asia, 24; North America, 20; Central America, 25. On the islands there are nearly twice as many as on the continents. Nearly all are situated near the sea. The shores and islands of the Pacific ocean contain the greatest number of volcanoes. A chain extending from the Aleutian Islands along the Asiatic coast contains 150, in active operation. Along the western coast of Asia there are about 80. In the Atlantic there is a ridge containing most of the rest. The remaining volcanoes of the earth radiate at right angles to these lines. There is an important line running from the Atlantic through the Mediterranean. These lines are parallel to the great lines of fracture in the earth's crust.

Many mountain chains have volcanoes in them, or parallel to them. Volcanoes are never found in areas of subsidence. They "are generally formed in comparatively recent strata. This seems to be connected with their relation to the sea; for recent strata are abundant about the sea-coast, and the most recent are now forming in the bed of the sea. The extinct volcanoes of France and Germany are in tertiary regions—possibly the retiring of the sea has extinguished them."

Some deny the *geological continuity of volcanoes*, and claim that they are all modern, by saying that all the older rocks are granite, and that lavas, etc., are all modern. But

granite has been formed in all ages of the world. We find it more frequently among the older rocks, because they, formed under pressure, have since been laid bare by denuding agencies. Volcanic products are not found among the older rocks, because they are easily washed away.

The scene of volcanic activity has been continually shifting. Volcanoes arise, reach their maximum, and decrease; but their activity appears elsewhere. Their histories are the same, except that in modern times their energy has declined. The history of their transfer is the history of the formation of coast lines.

Causes of Volcanic Action. No hypothesis has yet acquired the dignity of a theory. All the main facts are unquestionable; but any theory to account for them must explain—

1. The existence of a high temperature in certain parts of the earth's crust; and,

2. The presence of great quantities of water and gas imprisoned in the lava.

1. High temperature. As we descend into a mine the temperature increases, but with no regularity; sometimes averaging 1° for every fifty or sixty feet. If this law held good, as we descend further, a distance of twenty miles would change everything into liquid fire. The theory is untenable that the earth is a crust fifteen or twenty miles thick, enclosing a liquid. It is disproved by the light of astronomical facts, which clearly demonstrate that the minimum thickness of the earth's crust is four hundred miles, and it may be a solid sphere. That volcanoes are not openings in a common reservoir of fusible matter is shown by the following five proofs:

(1.) The crust, as proved by other reasoning, is far too thick.

(2.) Pressure exerted upon a liquid is equally transmitted in all directions, and hence, the crust would yield at the weakest points, and would not be confined to any one place.

(3.) Volcanoes in close proximity seem to be entirely independent; one is often in a state of eruption while the other is quiet.

(4.) We cannot deny the close connection between volcanoes and earthquakes; and we can prove that earthquakes never originate at depths greater than thirty miles, usually not more than seven or eight.

(5.) If a central sea of liquid fire existed, the lava would rise and fall in the craters of volcanoes like the tides in the ocean.

Hence, we conclude that volcanoes are openings into reservoirs more or less local and limited.

How, then, is this high temperature to be accounted for? The earth is a cooling mass, which we can prove cools and contracts more rapidly at the interior than on the exterior; the pressure thus results in a "lateral squeeze." This causes a folding of the earth's crust, which gives mountain chains and coast lines. "Mountain chains," says Le Conte, "are the lines along which the yielding of the surface to horizontal thrust has taken place." *This crushing of the rocky crust developes, by pressure and friction, an enormous amount of heat, sufficient in many places to fuse the rocks, and to produce eruption.* This is the present theory. It also explains the fact that volcanoes occur in lines, viz.: along the lines of fracture, just as in mountain chains.

2. The presence of imprisoned water. It is probable that the sea water gains access through great fissures.

Prof. Judd denies this, and accounts for the presence of water by the "ordinary system of circulation." But were it not sea water, it is evident that volcanoes would support themselves at a distance from the ocean. That water is intimately mingled and distributed through the earth, depends upon the power of numerous substances, when melted, of absorbing many times their extent of steam. This may be shown in an experiment with steam and sulphur.

To sum up, the proximity of the sea and the heat produced by lateral pressure and friction, account for volcanic phenomena.

Earthquakes are a series of elastic waves, propagated in the earth as sound is propagated in the air. *An earthquake is that portion of a vibration which reaches the earth's surface by a shock somewhere in the earth's crust.*

"A common and often very destructive accompaniment of earthquakes is formed as follows: The sudden upheaval of the sea bed lifts the superincumbent water to an equal extent, forming a huge *tidal wave.* These waves are often from 100 to 200 miles across their base, and from 60 to 70 feet in height." Their velocity is less than that of the wave in the earth, and hence the earthquake may be felt upon the shore an hour before the tidal wave appears. The earthquake in 1868, which desolated the coast of Peru, raised a tidal wave which reached the Sandwich Islands in twelve hours, and Japan four hours later.

Earthquakes produce permanent geological effects, the most obvious of which are the raising and depression of the coast. The whole south end of South America has been lifted out of the ocean largely during the present century.

Causes of earthquakes are certainly intimately connected with volcanic action. Three proofs may be given.

(1.) The areas of volcanoes and earthquakes are the same.

(2.) Earthquakes are often removed or relieved by the opening of volcanoes.

(3.) "Volcanic eruptions, especially those of the explosive type, are always preceded and accompanied by earthquakes."

This suggests that the cause of earthquakes is the *struggle of the pent-up steam and lava.* This explains some of the phenomena. But some earthquakes are to be accounted for by *the contraction of the earth as it cools;* the gliding and grinding of the particles and strata upon one another. Le Conte claims that all earthquakes are the effect of this second cause, but it seems probable that both these causes have their share in the production of earthquakes.

Slow elevations and depressions of the land with accompanying earthquakes. Among excellent examples of this phenomenon is the temple of Jupiter Serapis, at Puzzuoli. "This temple was, of course, above the sea level during the Roman period. After that period it sank until the sea level was twenty feet above the base. Now the floor of the temple is on a level with the sea. The changes were so slow that they were entirely insensible, and, in fact, unknown to the inhabitants." They are now gradually sinking. The pillars are monoliths forty feet high; for about twelve feet from the base they are perfectly smooth; next a section honeycombed by shells, and above this it is again smooth.

Such changes are found where volcanoes do not exist, and where there are no earthquakes. Sweden is such an example. Celsius stated that the sea was retreating. His opponents easily disproved his theory, because he had misconstrued the facts. The sea was not falling, but the land was rising. At the present time it is rising 5 or 6 feet a century. The coast rises in some places, and sinks in others. Across the sea, Greenland is undergoing subsidence. All deltas are gradually sinking. In every case, the land changes, and not the sea. If there were any change in the sea-level, the shore could not recede and advance in the same vicinity.

METAMORPHISM.

The sedimentary and igneous rocks have undergone little change, but there is a third class, called *metamorphic rocks*, which have changed radically since their origin. It is an intermediate class, graduating "on the one hand into the true, unchanged sediment; and, on the other, into true igneous rocks. The rocks of this class are stratified, like the sedimentary, but crystalline, and usually non-fossiliferous, like the igneous rocks." Their origin is, primarily,

sedimentary, but they have been subjected to heat and other agents, which have changed their structure, destroyed their fossils, sometimes even their bedding or laminated structure, and induced instead a crystalline structure. They are divided into three classes:

1. Those that retain their bedding.
2. Foliated or schistose.
3. Amorphous.

(1.) *Those rocks that retain their bedding.* (*a*) Among silicious rocks is found quartzite, made of crystalline granules. It is excessively hard, and if impurities are present, the structure is banded.

(*b*) Among argillaceous rocks we find clay slate. It is a common surface rock in New Jersey. When formed under pressure, it makes cleaved slate; *e. g.*, roofing slate.

(*c*) Calcareous. An important member is crystalline marble; *i. e.*, metamorphose limestone. It is plainly crystalline.

(*d*) Carbonaceous; *e. g.*, lead graphite is metamorphose coal.

(2.) *Foliated rocks* are those which tend to split into rudely parallel planes. The splitting is effected by the arrangement of the different minerals in layers or plates. These plates are usually crystalline. There is an endless variety of these rocks.

(*a*) Schists consist, essentially, of quartz, in which foliation is produced "by parallel layers of some other mineral. The prevailing mineral gives its name to the schist; *e. g.*, mica-schist, talcose-schist, hornblende-schist."

(*b*) Gneiss has the same composition as granite, but it is formed by layers of mica between layers of quartz and felspar. It is a metamorphized granite, and it runs, by insensible gradations, into the ordinary granite. It is the prevailing rock on Manhattan Island.

(3.) *Amorphous rocks* are those in which the bedding has been completely destroyed. In small masses they cannot be distinguished from igneous rocks. In this class belong many granites.

Proofs that metamorphic rocks are sedimentary in their origin. (1.) In many cases we can trace the same stratum from where it is obviously sedimentary to where it becomes metamorphic.

(2.) We can produce metamorphic rocks artificially; *e. g.*, the sandstone lining of iron furnaces becomes quartzite, and if heated under pressure it becomes crystalline.

(3.) Several kinds of metamorphic rocks are plainly stratified, which could not be if they were of igneous origin.

(4.) In certain exceptional cases, traces of fossils can be found in them.

The causes of Metamorphism and the conditions under which it occurs, are very obscure. "Local metamorphism is produced by direct contact with sources of intense heat, as when dykes break through stratified rocks." In such cases the heat bakes clay into slate; limestone into marble; coal into graphite, etc.

But heat alone is not enough to produce metamorphism. Pressure and water are also necessary. The pressure is only attainable at great depths. Recent experiments prove that water under pressure at 752° Fahr. reduces ordinary rocks to a viscous condition. If water is not present, it requires three times the weight of pressure and a temperature of from 3,000 to 4,000° Fahr. For all these reasons, it is obvious that metamorphic rocks can only be formed at great depths. Hence, "all the lowest and oldest rocks are metamorphic. The converse, however, viz.: that metamorphic rocks are always amongst the oldest, is by no means true. Metamorphism is not, therefore, a test of *age*."

A GENERAL SURVEY OF ROCK FORMATION.

It will be noticed that there is a cycle of rock formation constantly going on. Igneous rocks are decomposed; in the form of sediment they are borne down and deposited by the rivers; the mass thus formed becomes solidified into sedimentary rock; next, through the action of pressure, heat and water, it becomes metamorphic rock; and, finally, it is thrown out as igneous rock, to again start in the cycle. This cycle has never been interrupted, and all new products are subjected to the same process.

STRUCTURAL GEOLOGY.

ROCKS DESCRIBED AND CLASSIFIED.

Rock masses present themselves, stratified and unstratified, as already explained.

A layer is a single member, or bed, in a stratified rock.

A stratum is a collection of layers of similar mineralogical character, bound above and below by a rock of different character.

A formation is the whole series of strata which belong to a single geological age, and which are characterized by some peculiarity in their fossils.

Le Conte lays down three propositions, which underlie all geological reasoning:

1. "*Stratified rocks are, more or less, consolidated sediment.*"

2. "*Stratified rocks have been gradually deposited.*" Thus, the thickness of a rock gives a rough and relative estimate of the time used in its formation.

3. "*Stratified rocks were, originally, nearly horizontal.*" Hence, when strata are found tilted, twisted or folded, it follows that they have been disturbed. This dictum can be proved by the perpendicular position of the carboniferous stumps of trees in the bending strata of coal regions.

A fourth may be deduced from the three preceding :

4. *Unless strata have been very much disturbed, the order in which they lie is the order of their relative age.* We seldom find them horizontal, and in some cases their position is actually reversed.

The angle which an inclined stratum makes with the horizon is called its *dip*.

"The *strike* is the line of intersection of strata with a horizontal plane, or the direction of the outcrop of strata on a level surface. It is always at right angles with the dip." Many rocks have a double dip. Rarely does the dip remain constant for any distance or for a long period of time.

A ridge in a strata is called an *anticlinal;* the *trough*, a *synclinal.*

A dome is where the strata "dip up" to a common center.

A basin is formed wherever the strata dip down to a common center.

Outliers are patches of rock produced by foldings of the strata and denudations.

Faults are formed where the strata are broken across by violent treatment and one side is thrown up or down. A fault is seldom vertical. The side toward which the fault slopes is the side which is thrown down. They are important factors in mining.

"*Cleavage* may be defined as the easy splitting of any substance in planes parallel to each other," and is always produced by pressure exerted perpendicular to these planes.

A joint arises from the shrinkage of the rock as it sets or consolidates. The different rocks have characteristic joints; *e. g.*, limestone is jointed in regular cubes, slate shows rhomboidal shapes, other rocks hexagonal.

When *foldings* occur on a grand scale, as in mountain chains, they are the result of the lateral pressure produced by the shrinkage of earth.

Conformable rocks are those which overlie each other with

the same dip. Very frequently unconformable rocks are superimposed upon one another. There are two kinds of *unconformity.* "When one series rests (1) on the eroded surface, or (2) on the edges of another series, the two series are said to be unconformable. The fossils of two unconformable series differ always, and abruptly from each other."

An unconformity indicates two things:

1. That certain beds are raised up to form a part of dry land where they are eroded.

2. That these eroded or tilted strata have sunk beneath the sea, where new strata have been deposited upon them.

Gaps in geological history. Certain strata may have formed the land surface for thousands of years; during such a period they have received no fossils, and so give us no record of the geölogical history. We can only form a very rough estimate of the time by the amount of erosion, and we may get an equally rough estimate of the time of submergence. These gaps may often be bridged over by examination of the strata in other localities. Former geologists made many mistakes, because they had but little ground explored, and but few facts obtained. The step between the Cretaceous and Tertiary ages was very sudden. But the explorations in our Western Territories and in France have bridged over the gap, and probably, in time, all the geological gaps will be filled up. But a very small portion of the earth's crust is yet known, geologically; a spot here and there, and a vague idea of the formation of a few small areas. As exploration is extended, negative theories are being constantly disproved.

Classification of strata. It is plain that the best way to arrange them is in the order of their origin or age. The mineralogical constitution of a rock will not aid in classifying it, for the same body of water may deposit all kinds of rock—a conglomerate, a sandstone, a shale, etc.

Only one safe inference can be drawn from the mineralogy of a rock, viz.: It is always younger than the rock from which it has been formed. An imbedded fragment of a rock may aid us in determining comparative age.

The only valuable criterion in the classification of strata is the organic remains which the rock contains. Dana states the fundamental fact thus: "The life of the globe has changed with the progress of time. Each epoch has had its peculiar forms, and, moreover, the succession of life has followed a grand law of progress, involving a closer and closer approximation to those forms which now exist. It follows, therefore, that *identity of species proves approximate identity of age.*" Fossils of a certain age bear a certain undefinable stamp, which is unmistakable to the trained geologist.

Seven Geological Ages:

Azoic.	I.	Archaan (no certain proof of life).
Paleozoic.	II.	Silurian (age of invertebrates).
	III.	Devonian (age of fishes).
	IV.	Carboniferous (age of coal-making plants).
Mesozoic.	V.	Reptilian (age of reptiles).
Cenozoic.	VI.	Tertiary (age of mammals).
	VII.	Quaternary (age of man).

These ages have been deduced from examinations of small areas, but they are applicable to the whole earth, and will probably never have to be changed.

DYNAMICAL GEOLOGY—(Continued).

The Earth as a cooling body. The earth was formerly a heated vapor. The constituents of the earth were fused in a gaseous state. Next the gasses became liquid fire; and then a solid crust was formed, with perhaps a liquid interior. As the earth cooled, it became solid, and contracted, and

gave the lateral thrusts which constitute the chief agency of dynamic geology. It is this contraction which has determined the configuration of the earth's surface.

There is a great controversy now going on concerning this subject. Every conceivable theory finds some advocates. A fashionable one is, that there is a thin crust, with a liquid interior. It rests upon two false assumptions:

(1.) That the rate of increase of the temperature is uniform as we descend into the earth.

(2.) That the point of fusion for any given rock is constant at all depths.

The rate of increase of the temperature has been proved, by experiments in artesian wells, to vary much. The point of fusion is much altered by a difference of pressure. The higher the pressure the greater the heat required to fuse any given substance.

Astronomy helps us much in this subject. (1.) Hopkins proves that the precession motion of the earth could not take place if the earth had not a crust at least 800 miles thick; and, at the same time, that these motions are not inconsistent with the absolute solidity of the earth.

(2.) Sir William Thompson proved that if the earth were made of solid glass, the attraction of the moon would pull a wave of glass three feet high like a tide of water. Hence, the earth is a solid more rigid than glass.

(3). The specific gravity of the earth, as a whole, is much greater than that of the rocks which compose its crust; it being 5 or 6, while that of rocks is from 2½ to 3. Hence, the interior must be far denser than the crust.

We are safe, then, in asserting that THE EARTH IS A SOLID BODY.

THE END OF LECTURES OF SECOND TERM.